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DRAG OF CANOPIES AT TRANSONIC AND SUPERSONIC SPEEDS

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NATIONAL ADVISORY COMMITTEE
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RESEARCH MEMORANDUM

DRAG OF CANOPIES AT TRANSONIC AND SUPERSONIC SPEEDS

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SUMMARY

Area-rule analysis provides a good basis for the design of efficient canopies at transonic and supersonic speeds. However, detailed canopy design is important for minimizing the subsonic drag increment. Body indentation may be expected to reduce the canopy drag from 25 to 50 percent at low supersonic speeds. In general, the inclined flat windshield is as good as the vee windshield from a drag standpoint. The pressure drag of canopies can be adequately predicted with area-rule theory above Mach number 1.1.

INTRODUCTION

The design of pilot canopies for minimum drag is important for optimum performance of airplanes at high speeds. Recent tests indicate that the drag of conventional type canopies varies from 10 to 20 percent of the airplane drag above Mach number 1.0. In order to aid the designer in minimizing this drag penalty, the National Advisory Committee for Aeronautics has conducted several investigations to determine some of the basic drag properties of canopies, such as the effect of windshield shape, size, and location on drag, as well as the usefulness of the area rule for reducing and predicting the drag due to canopies. The purpose of this paper is to give a short account of these investigations with the view of providing a basis for the design of efficient canopies at transonic and supersonic speeds.

SYMBOLS

A — cross-sectional area

A_c — canopy frontal area

A_f — fuselage frontal area

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A_{max} maximum cross-sectional area

C_{D_O} zero-lift drag coefficient

ΔC_{D_O} zero-lift drag-rise (or pressure drag) coefficient

F fineness ratio

l total length of configuration

l_A forebody length

M Mach number

x longitudinal distance

RESULTS AND DISCUSSION

Canopy-Fuselage Total Drag

Windshield shape.- An example of the effect of windshield shape on drag is given in figure 1. The three configurations near the top of the figure were identical except for the shape of the windshield. The vee and flat windshields were derived from the round windshield. All three canopies had a frontal area equal to 0.165 the fuselage frontal area and an equivalent body fineness ratio of 7. The body is a drooped-nose forebody of fineness ratio 5.6. Both the canopies and body had elliptical cross sections. The total drag coefficients are for zero angle of attack and are based on the body frontal area. The tests were made in the Langley 8-foot transonic tunnel (ref. 1) and in the Langley 4- by 4-foot supersonic pressure tunnel (ref. 2) for the ranges of Mach number shown.

The comparison shows that windshield shape may have an important effect on drag at all Mach numbers. The vee windshield has about twice the subsonic drag increment of the flat windshield at high subsonic speeds, approximately 30 percent more drag than the flat windshield at transonic speeds, and slightly more drag than the flat and round windshields near Mach number 2.0. Calculations from pressure surveys (ref. 2) on the flat and vee windshields show that the lower drag for the flat windshield is associated with the flow expansions around the edges of the windshield so as to produce lower pressure over the canopy frontal projection.

The apparant superiority of the flat over the vee in this case is not necessarily representative of flat and vee windshields in general. In a second case, the incremental differences were smaller, and, in a third case, there was no measurable difference due to windshield shape. It is significant, however, that a flat windshield may be used without any drag penalty relative to a vee windshield.

Canopy size.- The effect of canopy size on drag is shown also in figure 1 (refs. 1 and 2). The frontal area of the large flat-face canopy was reduced about 40 percent, the fineness ratio was increased from 7 to 10, and the windshield sweepback was increased from 55° to 65°. These changes gave a large reduction in the canopy drag, reducing the drag increment by about 60 percent at supersonic speeds. It is evident from this comparison and others that minimum frontal area, high fineness ratio, and low windshield slope (ref. 3) for canopies on pointed bodies are necessary for low drag above Mach number 1.0.

Canopy-Fuselage Pressure Drag

The effect that canopy variables have on the pressure drag or drag rise can be predicted in a qualitative way with the transonic area rule (ref. 4) and in a quantitative way with the supersonic area-rule theory (refs. 5 and 6). The test drag-rise coefficients used for the comparisons were obtained by subtracting the drag coefficient at a Mach number of 0.8 from the corresponding drag coefficients at higher Mach numbers.

Windshield shape and canopy size.- A comparison of the normal cross-sectional area distributions of the flat and vee windshields with the measured drag rises near $M = 1.0$ (fig. 2) shows that the results are in agreement with the concept of the transonic area rule. The vee windshield has a somewhat more rapid rate of development of cross-sectional area than the flat windshield, and, hence, a slightly greater drag rise at transonic and supersonic speeds. As the Mach number increases, the effect of windshield shape on the pressure drag decreases.

When the fineness ratio of the large flat-face canopy was increased from 7 to 10 by reducing its frontal area, the rate of development of its cross-sectional area was improved markedly (fig. 2), giving a smoother overall slope distribution on its area diagram and considerably less pressure drag throughout the Mach number range (fig. 2).

The theoretical variations (fig. 2) were computed for a range of Mach numbers from 1.0 to 1.41. The theory predicts the relative effects of changing windshield shape and canopy size, as well as the order of magnitude of the pressure drag above $M = 1.1$. The theoretical values are high for the canopy-body combinations; however, the agreement is within 15 percent above $M = 1.1$. This agreement is good in view of the fact that the theory gives only a first-order approximation of the total pressure drag. It should be remembered, however, that there may be significant differences in the subsonic drag level which would affect the total drag at supersonic speeds.

Canopy location.- The results in figure 3 were obtained from zero-lift rocket-model tests of canopy-fuselage combinations by the Langley Pilotless Aircraft Research Division. A flat-face canopy of fineness ratio 7, windshield sweepback of 63°, and circular cross section was tested in three longitudinal positions between the nose and maximum-diameter station of a parabolic fuselage, as is shown in the figure. The comparisons show that moving the canopy rearward to the maximum-diameter station gives increasing values of pressure drag. For the present case, the incremental drag increased about 20 percent by moving the canopy from the forward to the rearward position at supersonic speeds. The rearward displacement of the canopy increases the rate of development of normal cross-sectional area and gives more frontal area, which, according to the transonic area rule, corresponds to increasing unfavorable interference and higher drag. The supersonic area rule theory predicts the effect of rearward displacement, and, as in the case of the earlier comparisons, gives fairly good predictions of the total pressure drag above $M = 1.1$.

Body indentation.- The aforementioned tests show that the canopy drags may be high. For canopies having about one-sixth the body frontal area, the canopy pressure drag may be as high as the fuselage pressure drag. A possible solution to this problem, recently investigated by the Langley Pilotless Aircraft Research Division, is body indentation according to the transonic area rule to reduce the pressure drag. Figure 4 shows the results of such a symmetrical body modification on the pressure drag of canopies having flat and vee windshields. The symmetrical indentations used were designed to cancel the exposed canopy cross-sectional areas normal to the body axis. The indentations reduced the fuselage volume by approximately 3 percent.

The normal area indentation produced substantial reductions in the total pressure drag of both the flat and vee windshields (fig. 4) at transonic and supersonic speeds. The test results for the flat windshield are compared with the theoretical pressure drags for both the indented and original configurations in this figure. The theory indicates a large reduction in pressure drag due to indentation and shows that the effectiveness of the transonic indentation diminishes with increasing Mach number. The actual reduction in drag is slightly less than one-half of that predicted; nevertheless, the actual reduction is an appreciable part of the canopy drag.

These tests and others show that $M = 1.0$ indentations may be expected to give from 25 percent to 50 percent reduction in canopy drag at low supersonic speeds. Greater reductions may be possible from supersonic indentations or unsymmetrical indentations.

Canopy-Airplane Drag

The results just described are applicable, more or less, to airplanes having a smooth total normal area distribution for the body, wings, and other components. For a more practical case, where the airplane area diagram has a bump due to the wing, the optimum canopy size and location may depend, to a large extent, on designing the canopy to make the total normal area distribution smooth, as is shown in figure 5. The configuration is a fighter airplane, with a canopy modification that was recently tested in the Langley 8-foot transonic tunnel. The original model had a small canopy and a poor area distribution in the region of the wing and small canopy. The canopy volume was almost doubled and its fineness ratio was increased to make the total airplane area distribution smooth. As a result, the total drag coefficient (based on wing plan-form area) was reduced about 4 percent and the pressure drag by approximately 7 percent at $M = 1.13$. The reductions at transonic speeds were less, with no reduction being noted below a Mach number of 0.9.

CONCLUSIONS

Area-rule analysis provides a good basis for the design of efficient canopies at transonic and supersonic speeds. However, detailed canopy design is important for minimizing the subsonic drag increment. The canopy should be so designed as to provide, together with the airplane, a smooth overall area distribution, it being kept in mind that minimum frontal area, low windshield slope, and high fineness ratio for canopies are compatible with low drag. Body indentation for canopies according to the transonic area rule may be expected to reduce the canopy drag from 25 to 50 percent at low supersonic speeds. In general, the inclined flat windshield is as good as the vee windshield from a drag standpoint. The order of magnitude of the pressure drag of canopies on pointed-nose fuselages can be adequately predicted with area-rule theory above Mach number 1.1.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 1, 1955.

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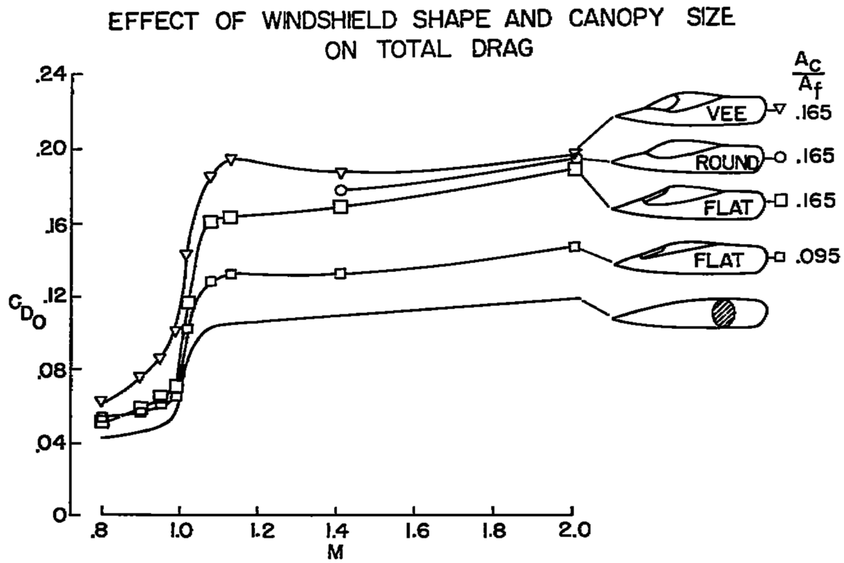

Figure 1

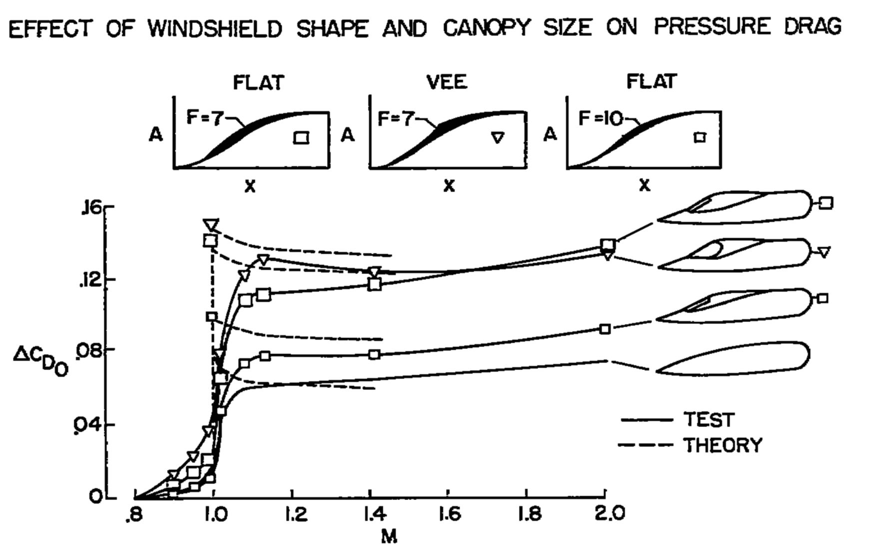

Figure 2

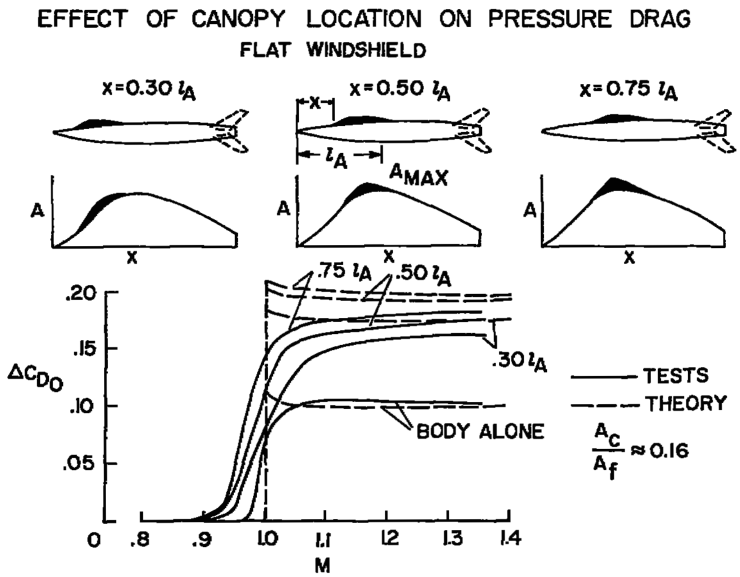

Figure 3

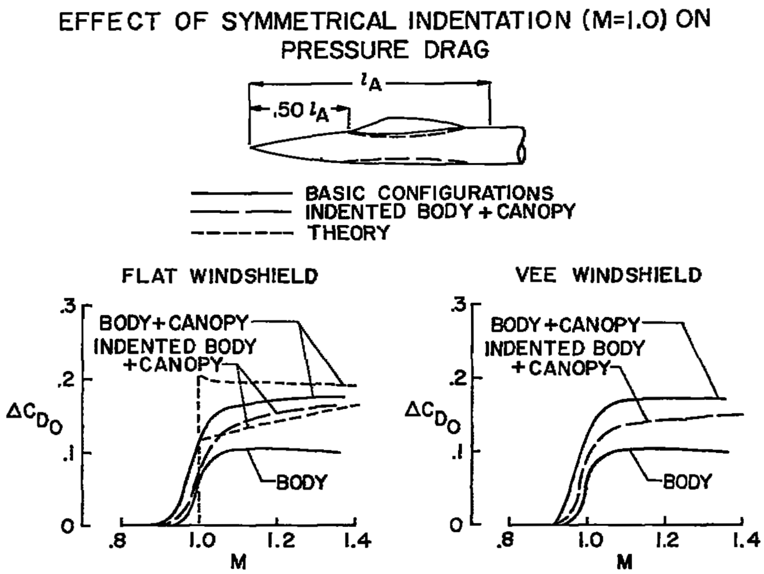

Figure 4

CANOPY MODIFICATION TO CONFORM WITH COMPLETE CONFIGURATION

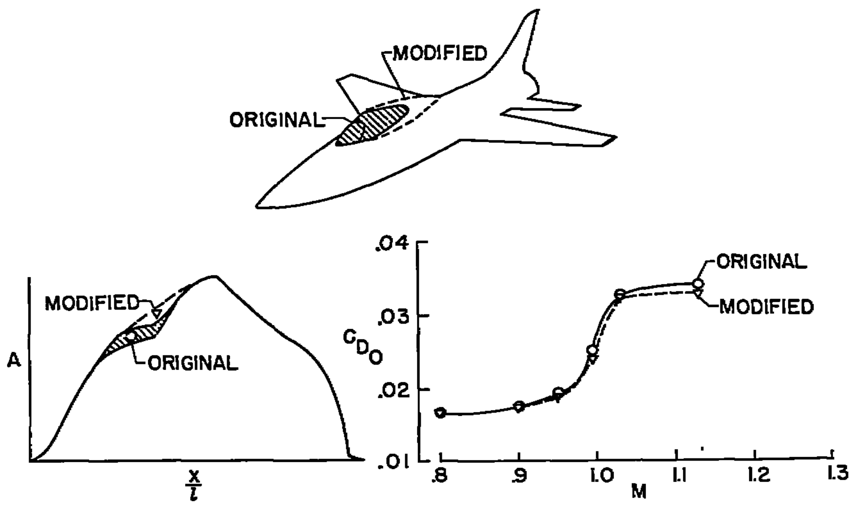

Figure 5

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